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RESEARCH MEMORANDUM

PRELIMINARY RESULTS OF NACA TRANSONIC FLIGHTS OF THE XS-1 AIRPLANE WITH 10-PERCENT-THICK WING AND 8-PERCENT-THICK HORIZONTAL TAIL

By

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

WASHINGTON
OCT 13 1948

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SUMMARY

The NACA is conducting a detailed flight-research program in the transonic speed range, utilizing the rocket-powered Bell XS-1 airplane with the 10-percent-thick wing and 8-percent-thick horizontal tail. Before this detailed program was started, the NACA made a series of exploratory flights to determine the operating limits of the airplane. ~~with the thicker surfaces.~~ This report presents results of this series of flights to a Mach number of 1.06 at altitudes of about 40,000 feet.

The data show that there is a gradual change of trim in the nose-down direction as the Mach number is increased from 0.78 to 0.99 while above this Mach number there is a change in trim in the nose-up direction. The elevator effectiveness in producing acceleration decreases to a minimum at a Mach number of 0.99. The elevator forces required to fly from subsonic speeds up to a Mach number of 1.06 at about 40,000 feet are light, never exceeding 30 pounds. The rudder effectiveness is very low at Mach numbers near 1.0, and the rudder forces are light. An intermittent lateral oscillation is present at both high and low Mach numbers.

INTRODUCTION

Since the acceptance tests of the XS-1 airplane (references 1 and 2) were completed, the two airplanes have been put into operation for research purposes. One of these airplanes, which has an 8-percent-thick wing and 6-percent-thick horizontal tail, has been used by the U. S. Air Force, Air Materiel Command Flight Test Division, in an accelerated transonic-flight-research program with the cooperation of the NACA. The results of this program were reported in references 3 to 5, which presented data that showed flight beyond a Mach number of 1.0 to be feasible with this airplane. The NACA is conducting a detailed flight-research program in the transonic speed range using the other XS-1 airplane which has a 10-percent-thick wing and an 8-percent-thick horizontal tail. Before this detailed flight-research program was started, however, the NACA made a series of exploratory flights to determine the operational limits of the XS-1 airplane with the thicker surfaces. These tests showed that flight at speeds in excess of Mach number 1.0 is possible with this airplane also. The results of these preliminary NACA flights pertaining to the stability and control characteristics are presented in this report. Results of the wing and tail loads measured during these flights will be presented in a separate report.

SYMBOLS

M	Mach number corrected for error in measurement of static pressure
ΔM	error in Mach number due to error in measurement of static pressure (ΔM = Corrected Mach number - Uncorrected Mach number)
i_t	stabilizer setting, degrees
W	airplane weight, pounds
δ_e	elevator position, degrees
δ_a	right aileron position, degrees
δ_r	rudder position, degrees
F_e	elevator wheel force, pounds
F_a	aileron wheel force, pounds
F_r	rudder pedal force, pounds
β	sideslip angle, degrees
$\Delta\alpha_t$	change in angle of attack of stabilizer, degrees
$\Delta\delta_e$	change in elevator position, degrees
C_{N_A}	airplane normal-force coefficient (nW/qS)

H	pressure altitude, corrected for position error, feet
g	acceleration of gravity, feet per second, per second
q	dynamic pressure, pounds per square foot
n	normal acceleration, gravitational units

AIRPLANE

Both the pertinent dimensions and a description of the XS-1 airplane utilized in the NACA transonic-research program are given in the three-view drawing and photographs presented as figures 1 and 2. Detailed physical characteristics are tabulated in reference 1.

Since the weight of fuel and oxidizer required for rocket operation is large in comparison to the airplane weight, it would be expected that the gross weight and center-of-gravity position might change considerably during a flight. In order to determine the weight and center-of-gravity position of the airplane in flight, the airplane was weighed on the ground in a series of configurations corresponding to flight conditions. The results of these weighings are as follows:

Launching:
- Weight, pounds 12,200
- Center-of-gravity position, percent M.A.C. 22.5

Completion of power flight when jettisoning is initiated:
- Weight, pounds 7600
- Center-of-gravity position, percent M.A.C. 20.3

Landing:
- Weight, pounds 7024
- Center-of-gravity position, percent M.A.C. 24.24

INSTRUMENTATION

The instrumentation of the airplane consists of:

(1) Standard NACA internal recording instruments which record:

(a) Indicated airspeed
(b) Pressure altitude
(c) Acceleration (normal, longitudinal, and transverse)
(d) Rolling or pitching velocity
(e) Sideslip angle
(f) Control positions (elevator, aileron, rudder, and stabilizer)
(g) Control operating forces (elevator, aileron, and rudder)

(2) A 12-channel Consolidated oscillograph which records:

(a) Right wing aerodynamic shear and bending load
(b) Right and left horizontal tail aerodynamic shear and bending loads

(3) A sixteen millimeter GSAP camera to photograph the pilot's instrument panel

(4) A six-channel NACA radio telemeter and a Consolidated oscillograph at the ground telemeter station which record:

(a) Indicated airspeed
(b) Pressure altitude
(c) Normal acceleration
(d) Elevator angle
(e) Stabilizer angle
(f) Right aileron angle
(g) Times at which radar data box camera records tracking data

(5) A modified SCR 584 radar unit and a sixteen millimeter radar data box camera to photograph tracking data from the SCR 584.

The data from the internal recording instruments and the oscillograph are synchronized by a common timer. These data in turn are synchronized with the telemetered data and the radar data box camera frames by recording the internal timer signals, the data box camera frame counter signals, and the telemeter timer simultaneously on the continuous telemetered record made on the Consolidated recorder in the telemeter ground station. The data obtained from the camera photographing the pilot's instrument panel are related to the remainder of the recorded data by noting the frames where the pilot actuated the data switch and noting the times when data were recorded.

A comparison between internal and telemetered recording of data was presented in reference 3. In the present report, all data presented were obtained from the internal instruments.

The SCR 584 radar set was modified for longer range and incorporated an M-2 optical tracking unit to permit remote control of the unit and thus eliminate the hunt inherent with the radar when tracking is done automatically. The radar data box camera recorded values of radar slant range, elevation, and azimuth which are used to obtain the airplane geometric altitude throughout the flight.

The elevator angles presented in this report were measured at the center line of the elevator torque tube at the fuselage center line with respect to the stabilizer. The stabilizer angles were measured with respect to the fuselage center line, and the rudder and right aileron angles were measured with respect to their neutral positions. The airspeed head used was a Kollsman "High Speed" type and was mounted on a boom one chord length ahead of the left wing tip.

TESTS, RESULTS, AND DISCUSSION

Flight testing with the XS-1 airplane is complicated by a number of factors not present in normal flight-test work. This is caused primarily by the characteristics of the rocket power plant. Since the thrust can be varied only in increments of about 1500 pounds, it is difficult to obtain stabilized conditions. As stated before, the high rate of propellant consumption, inherent in rocket engines, causes large changes in weight and center-of-gravity location during flight. This makes the obtaining of data for comparable normal-force coefficients and center-of-gravity positions very difficult. Since the duration of powered flight is only a few minutes, it is difficult to obtain steady flight or any series of maneuvers at high Mach numbers.

A calibration of the airspeed head has been made up to a corrected Mach number of 1.06 by means of the radar tracking method described in reference 6. The results of the calibration are given in figure 3 as a plot of the ratio of error in Mach number ΔM to the corrected Mach number M against corrected Mach number. The curve is applicable to the data presented in this report within ±1 percent of corrected Mach number. The rapid rise in error in recorded Mach number and the abrupt drop at a Mach number of 1.03 are in general agreement with previous data presented in references 4 and 5.

The variation of control-surface positions and forces and sideslip angle with Mach number is shown in figure 4. These data were selected from runs made in straight flight with two stabilizer settings for an essentially constant normal-force coefficient of about 0.31. No record was obtained of sideslip angle for the data taken with

0.7° stabilizer incidence. Although during each of these runs the center-of-gravity ranges are not the same, they are believed to be close enough for comparison of data.

Figure 4 shows that with 2.2° stabilizer incidence, the elevator moved up as the Mach number increased and reached full-up at $M = 0.93$ with a pull force of about 30 pounds. At the highest Mach number, 0.935, the airplane was not completely trimmed and more elevator would have been used had it been available. Therefore, for the next flight a stabilizer incidence of 0.7° was used. The variation of elevator position and force with Mach number was essentially the same as with 2.2° stabilizer incidence. Above a Mach number of 0.93, however, the pilot reported that the elevator effectiveness was very low and he could not be sure of the trim position of the elevator. Thus, the large changes in elevator position near $M = 1.0$ should not be construed to indicate completely a trim change.

To illustrate further the decrease in elevator effectiveness, a time history of the portion of the flight at $M = 0.99$ is shown in figure 5 where the pilot slowly moved the elevator from full-up to almost full-down. The airplane responded slightly as shown by the decrease in normal acceleration and normal-force coefficient. The Mach number increased slightly during this run. The change in lift for this large elevator motion was, however, largely within the range of normal-force coefficients of figure 4. The small change in lift resulting from the large change in elevator deflection can be attributed to low elevator effectiveness and high stability. The relative elevator effectiveness was determined from the data of figure 4 and is shown in figure 6 as a function of Mach number. Because the tail lift may vary nonlinearly with elevator deflection, the data of figure 6 show only the average effectiveness over the deflection ranges used. Figure 6 shows that $\frac{\Delta\alpha_t}{\Delta\delta_e}$ is decreasing continually with increase in Mach number and decreases 50 percent between $M = 0.78$ and $M = 0.93$.

A time history of a turn made at a Mach number above 1 is presented in figure 7. Elevator position and force data for this and other turns as well as the push-down shown in figure 5 are presented in figure 8. The data for the push-down were taken at $M = 0.99$ and the data for the turn above Mach number 1.0 were taken at $M = 1.04 \pm 0.01$. The stability parameters $\frac{d\delta_e}{dC_N}$ and $\frac{F_e}{n}$ from these data are plotted against Mach number in figure 9. Although these data are not strictly comparable because of the differences in altitude, stabilizer incidence, and center-of-gravity position, some conclusions can be drawn since it is probable that the changes in Mach number are the predominating influence. The value of $\frac{d\delta_e}{dC_N}$ increases from a low speed value of 2° to a value of 113° at $M = 0.99$, indicating almost complete loss of elevator effectiveness in producing acceleration. The value of $\frac{d\delta_e}{dC_N}$ then decreases to about 85° at $M = 1.04$. The value of $\frac{F_e}{n}$ increases similarly from a value of 6 pounds per g at $M = 0.68$ to a value of about 72 pounds per g at $M = 0.99$. For a Mach number of 1.04 the stick force per g decreases to a value of 52 pounds.

In figure 7 at approximately 22 seconds the rocket power was turned off. The airplane decelerated through the transonic speed range in about 8 seconds while the elevator position was held fairly constant. The deceleration was accompanied by rapid changes in normal acceleration caused by the elevator being in the wrong position as the airplane left the Mach number range where the elevator was ineffective. This disturbance occurs every time the airplane decelerates in this range of Mach number. The changes in normal acceleration were relatively small in magnitude.

The pilot reported a left-wing heaviness at high speed. The aileron-angle and aileron-force curves for the two flights shown in figure 4 are inconsistent, and except at Mach numbers above 1.0 the forces are usually less than the control system friction of ± 10 pounds. At Mach numbers above 1.0 right aileron angle and force are used to balance the left-wing heaviness. Turnmeter data are missing for these flights and, although the data were obtained when the transverse acceleration was zero, it is probable that some of the data were obtained while rolling, which would account for the differences in aileron angle between the two runs.

The pilot reported the rudder was very ineffective in producing sideslip at Mach numbers near 1.0. Figure 5 shows that at a Mach number of 0.99 deflecting the rudder approximately 4° produced no transverse acceleration. The rudder forces were light throughout the speed range.

An intermittent lateral oscillation of small amplitude and a period of between one and two seconds has been noticeable in all flights with this airplane. The pilot stated the oscillation was very annoying and made precision flying difficult. Intermittent traces of this oscillation are evident on the transverse acceleration record of figure 5. If a large amplitude oscillation is initiated in the airplane, it will damp to small amplitude rapidly, but the small amplitude oscillation will persist. The oscillation does not appear to be solely a transonic phenomena because it occurs at both low and high Mach numbers.

CONCLUSIONS

From flights at transonic speeds of the XS-1 airplane having a 10-percent-thick wing and an 8-percent-thick horizontal tail, the following preliminary conclusions may be drawn:

1. There is a gradual nose-down change in trim as the Mach number is increased from 0.78 to 0.99 and a change in the nose-up direction to $M = 1.05$.

2. The elevator effectiveness decreases about 50 percent as the Mach number increases from 0.78 to 0.93 and is so low at Mach numbers above 0.93 that it has been difficult to establish the elevator angles actually required for trim.

3. The elevator forces required to fly from subsonic speeds up to a Mach number of 1.06 at about 40,000 feet are light, never exceeding about 30 pounds.

4. The elevator effectiveness in producing acceleration decreases to a minimum at $M = 0.99$.

5. The rudder effectiveness was low at Mach numbers near 1.0 and the rudder forces were light.

6. There is an intermittent lateral oscillation of small amplitude present at both high and low Mach numbers.

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MLE

REFERENCES

1. Williams, Walter C., Forsyth, Charles M., and Brown, Beverly P.: General Handling-Qualities Results Obtained during Acceptance Flight Tests of the Bell XS-1 Airplane. NACA RM No. L8A09, 1948.

2. Beeler, De E., and Mayer, John P.: Measurements of the Wing and Tail Loads during the Acceptance Tests of Bell XS-1 Research Airplane. NACA RM No. L7L12, 1948.

3. Drake, Hubert M., McLaughlin, Milton D., and Goodman, Harold R.: Results Obtained during Accelerated Transonic Tests of the Bell XS-1 Airplane in Flights to a Mach Number of 0.92. NACA RM No. L8A05a, 1948.

4. Williams, W. C., and Beeler, De E.: Results of Preliminary Flight Tests of the XS-1 Airplane (8-Percent Wing) to a Mach Number of 1.25. NACA RM No. L8A23a, 1948.

5. Stanley, R. M., Sandstrom, R. J., Yeager, Charles E., and Williams, Walter C.: Air Force Supersonic Research Airplane XS-1. Rep. No. 1, U. S. Air Force, Jan. 9, 1948.

6. Zalovcik, John A., and Wood, Clotaire: Static-Pressure Error of an Airspeed Installation on an Airplane in High-Speed Dives and Pull-Outs. NACA RB No. L5K29a, 1946.

SECRET

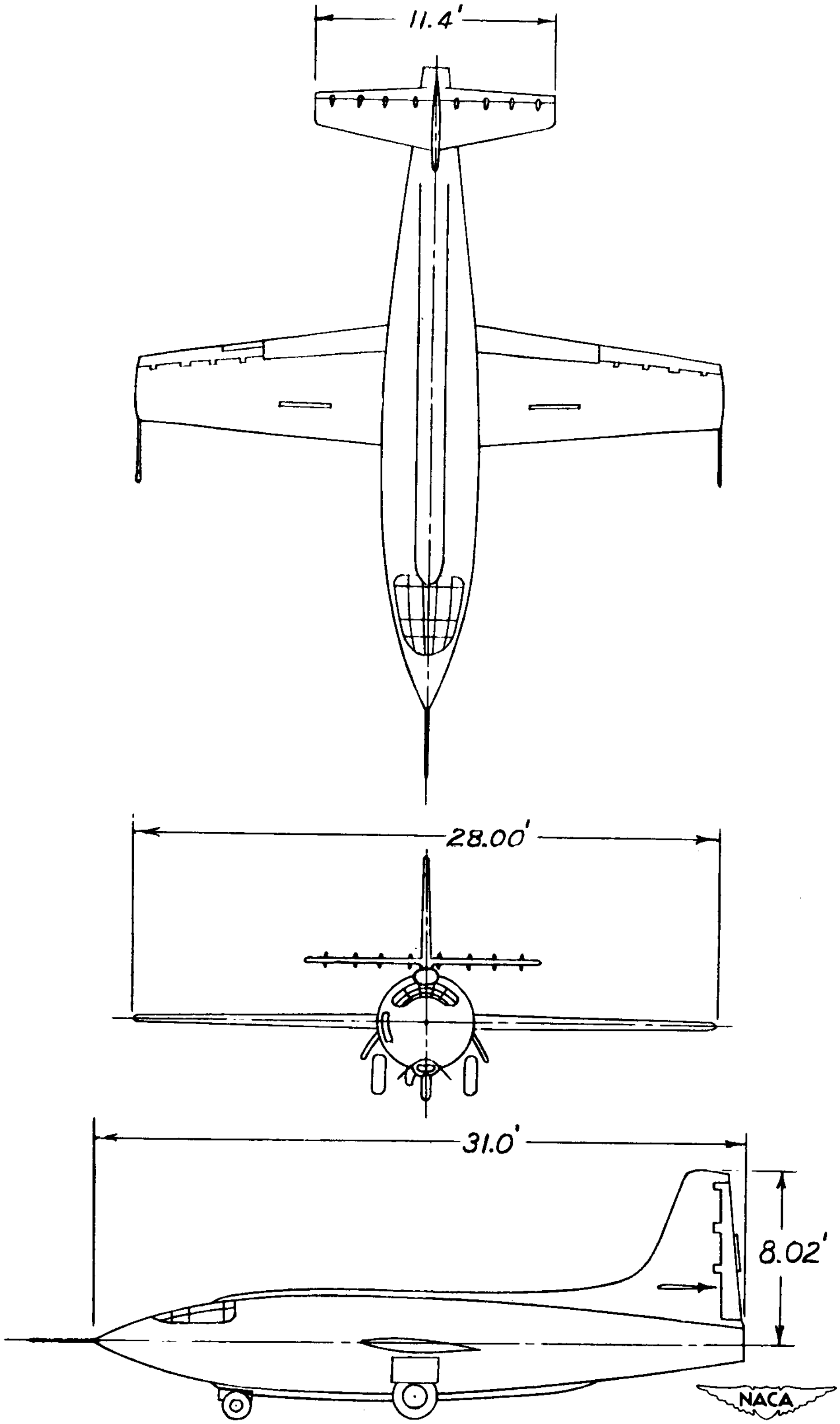

Figure 1.- Three-view drawing of XS-1.

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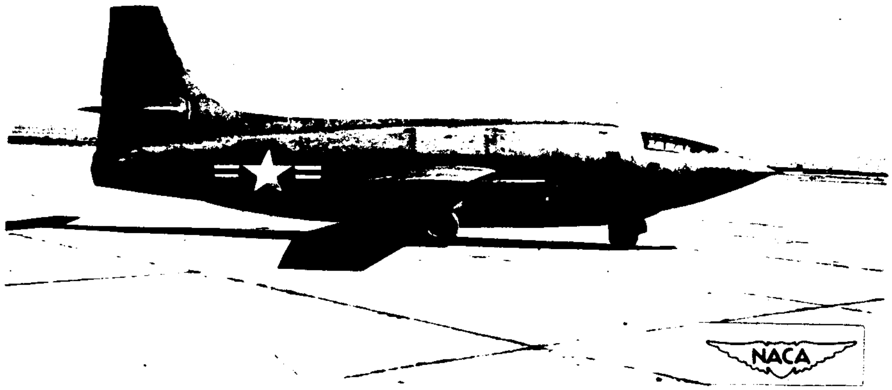
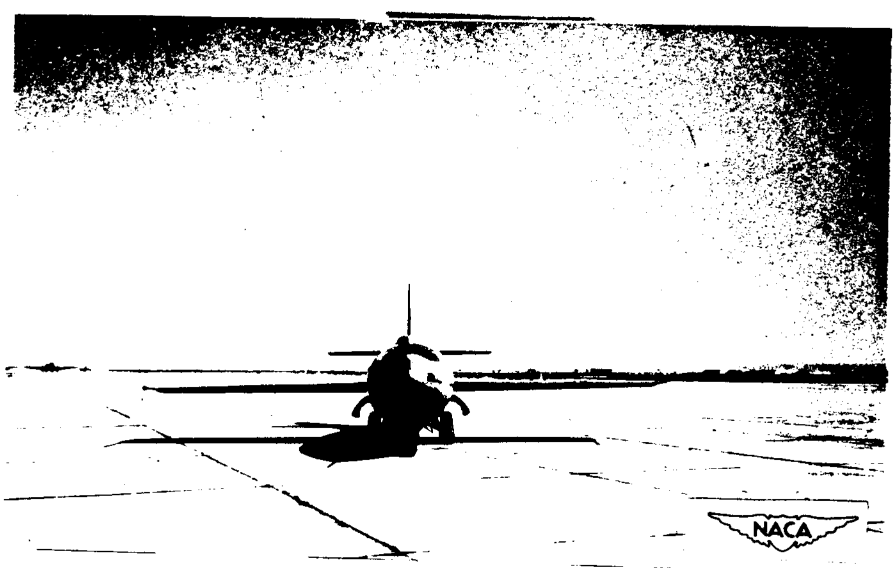


(a) Side view.



(b) Front view.

Figure 2.- Photograph of XS-1 airplane.

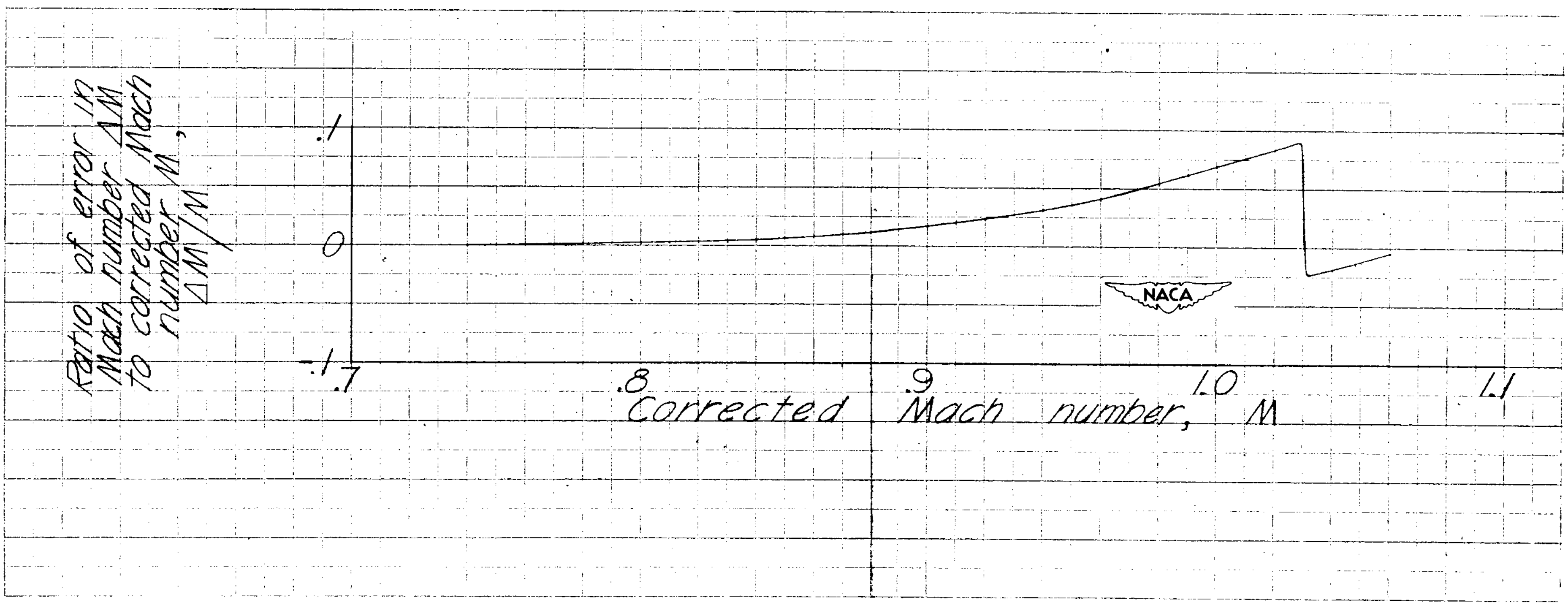


Figure 3.- Airspeed calibration of XS-1 airplane.

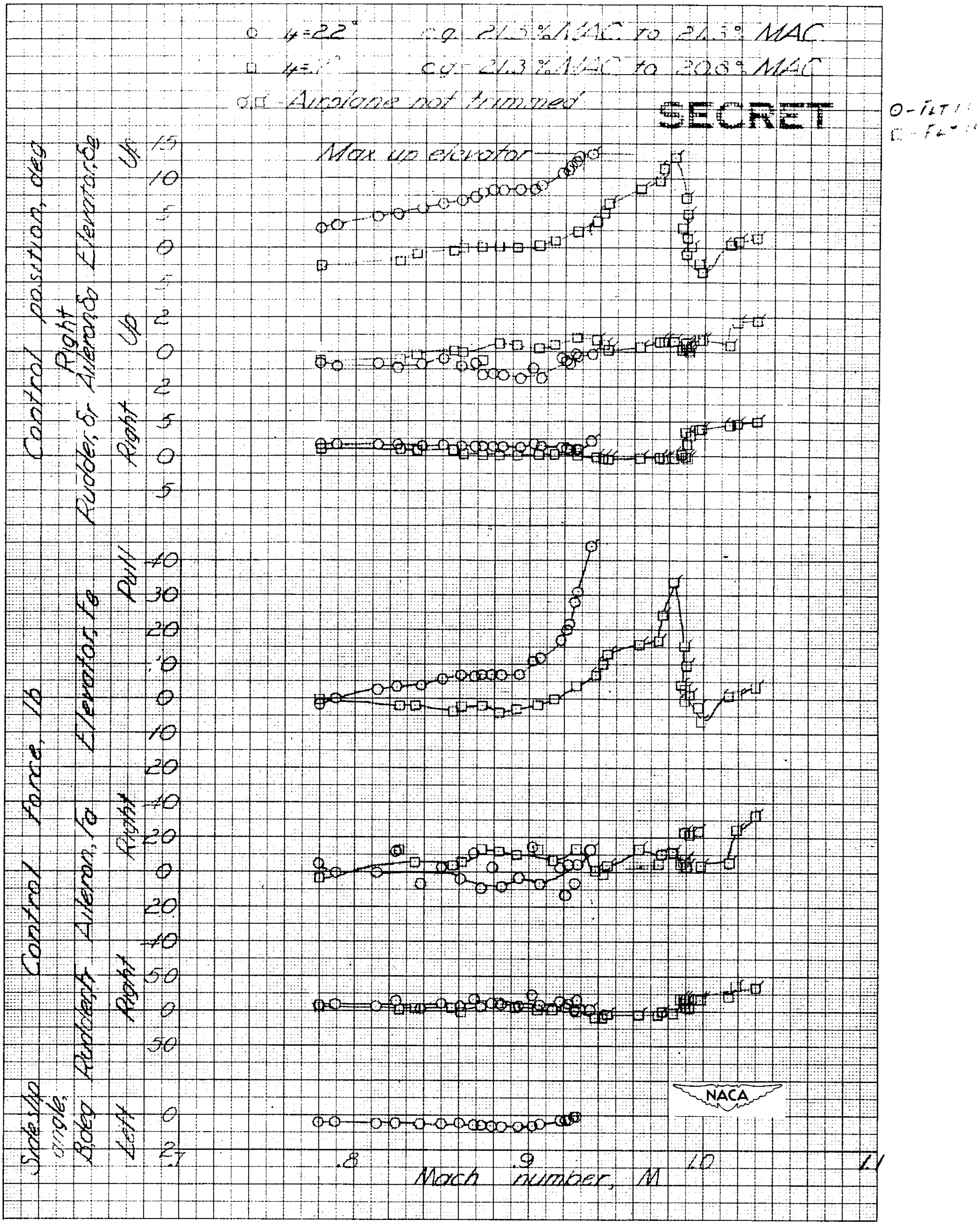


Figure 4.- Variation of measured quantities with Mach number. XS-1 airplane. 41,000 feet pressure altitude. $C_{N_A} = 0.31 \pm 0.05$.

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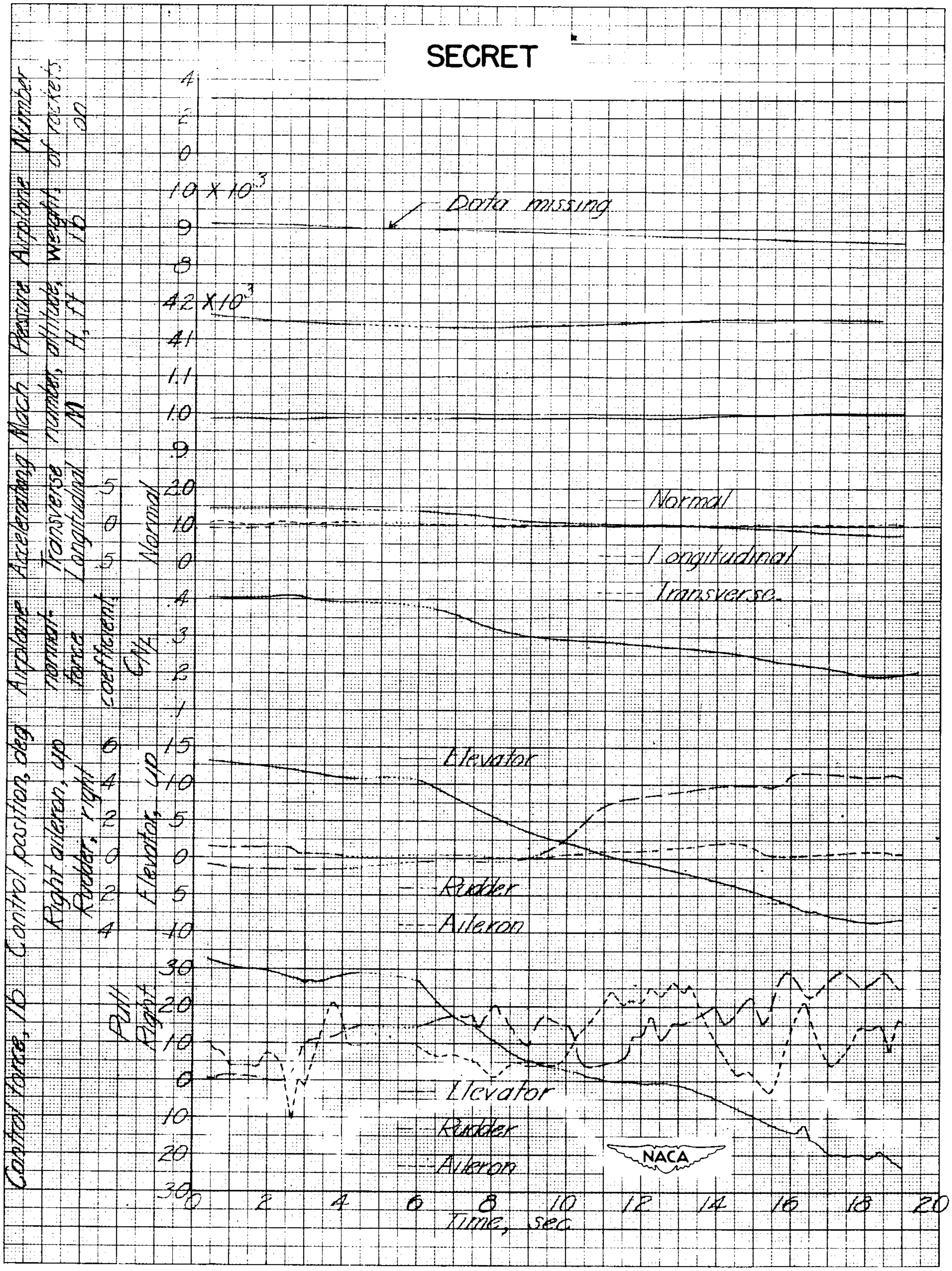

Figure 5.- Time histories of measured quantities during a push-down at M = 0.99. XS-1 airplane. Center of gravity = 21.1 percent mean aerodynamic chord to 20.9 percent mean aerodynamic chord, $i_t = 0.7^{\circ}$.

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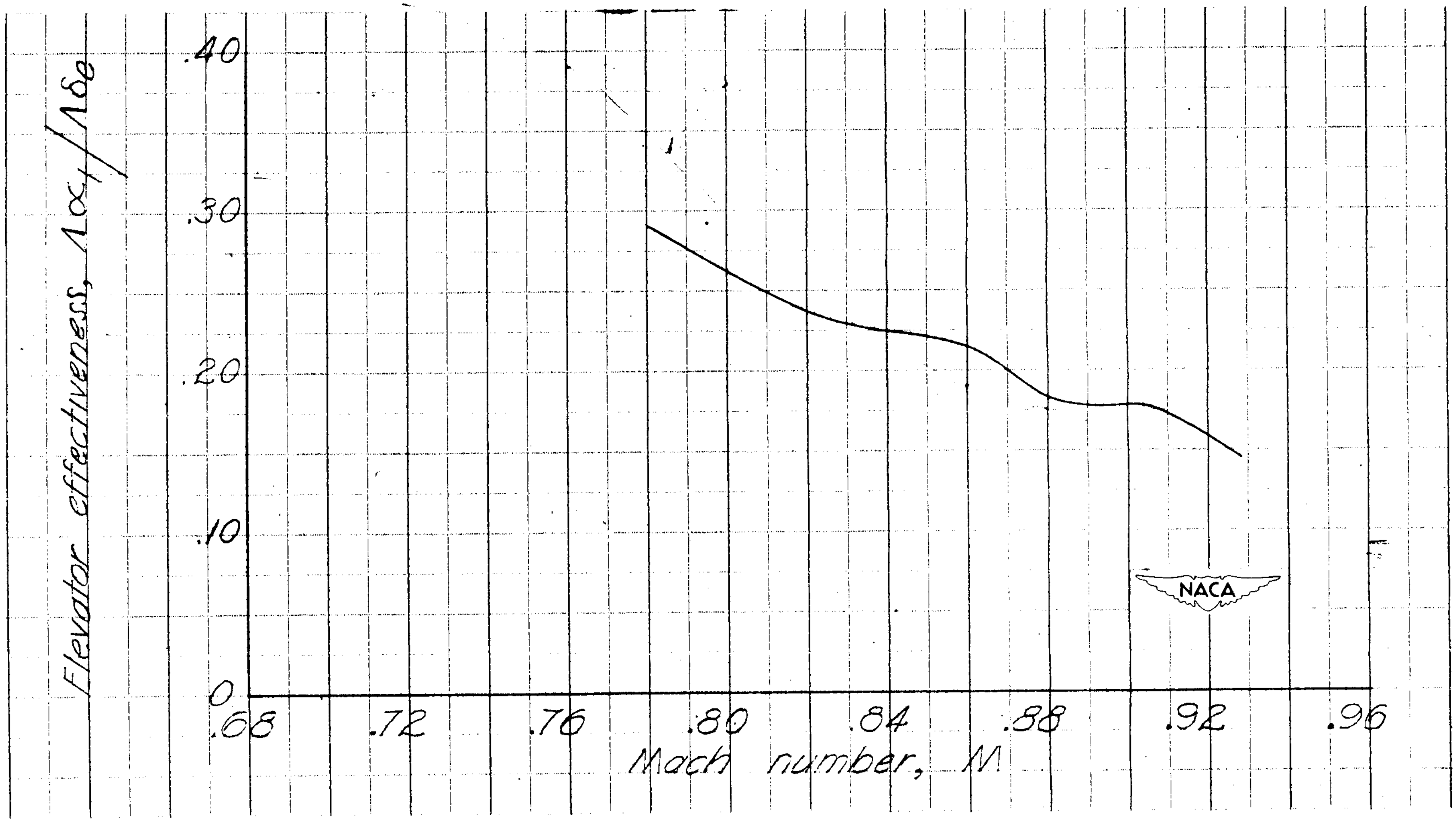

Figure 6.- Variation of relative elevator-stabilizer effectiveness with Mach number. XS-1 airplane. 41,000 feet pressure altitude.

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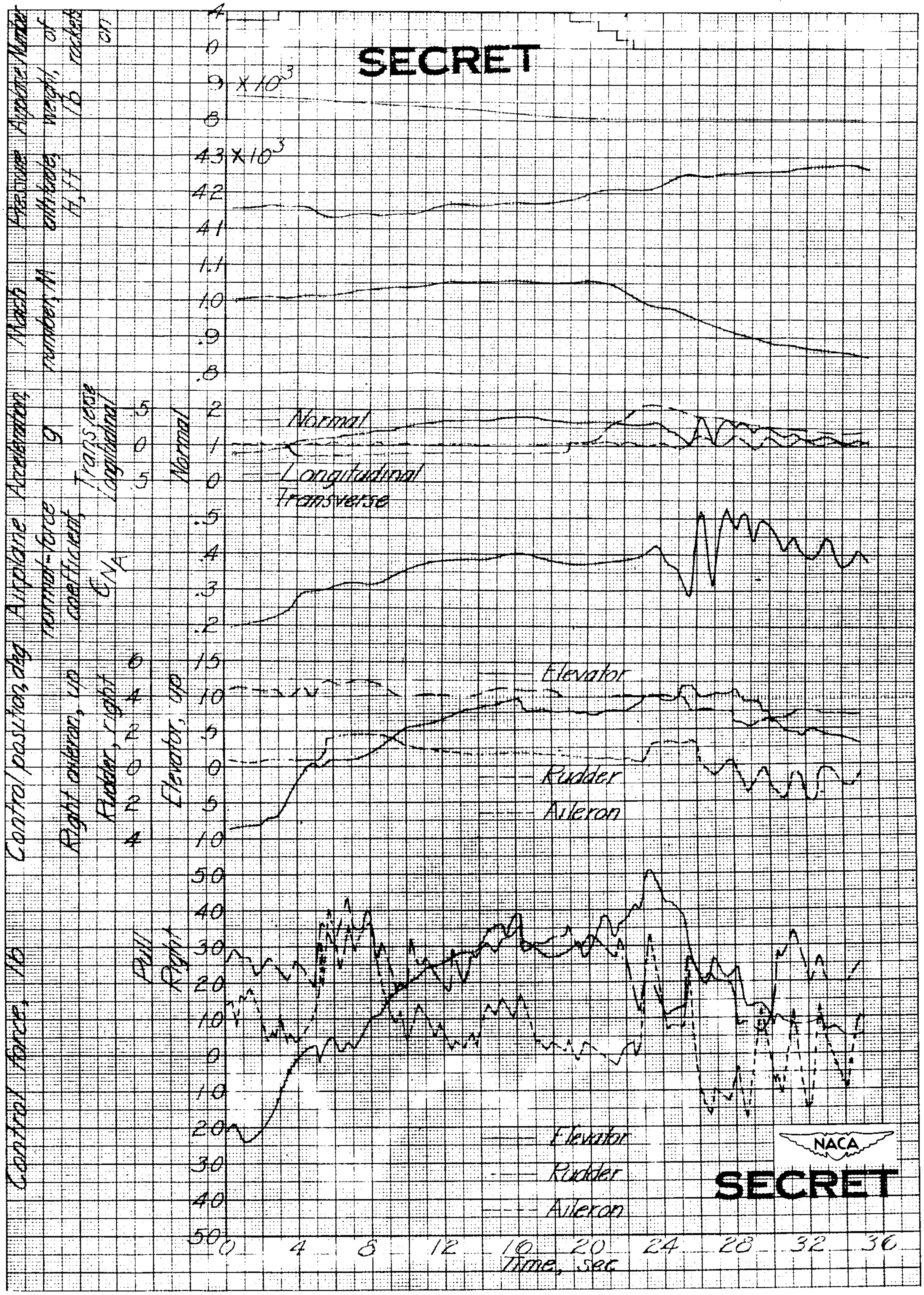

Figure 7.- Time history of measured quantities during a turn above M = 1.00. XS-1 airplane. Center of gravity = 20.9 percent mean aerodynamic chord to 20.6 percent mean aerodynamic chord, $i_t = 0.7^{\circ}$.

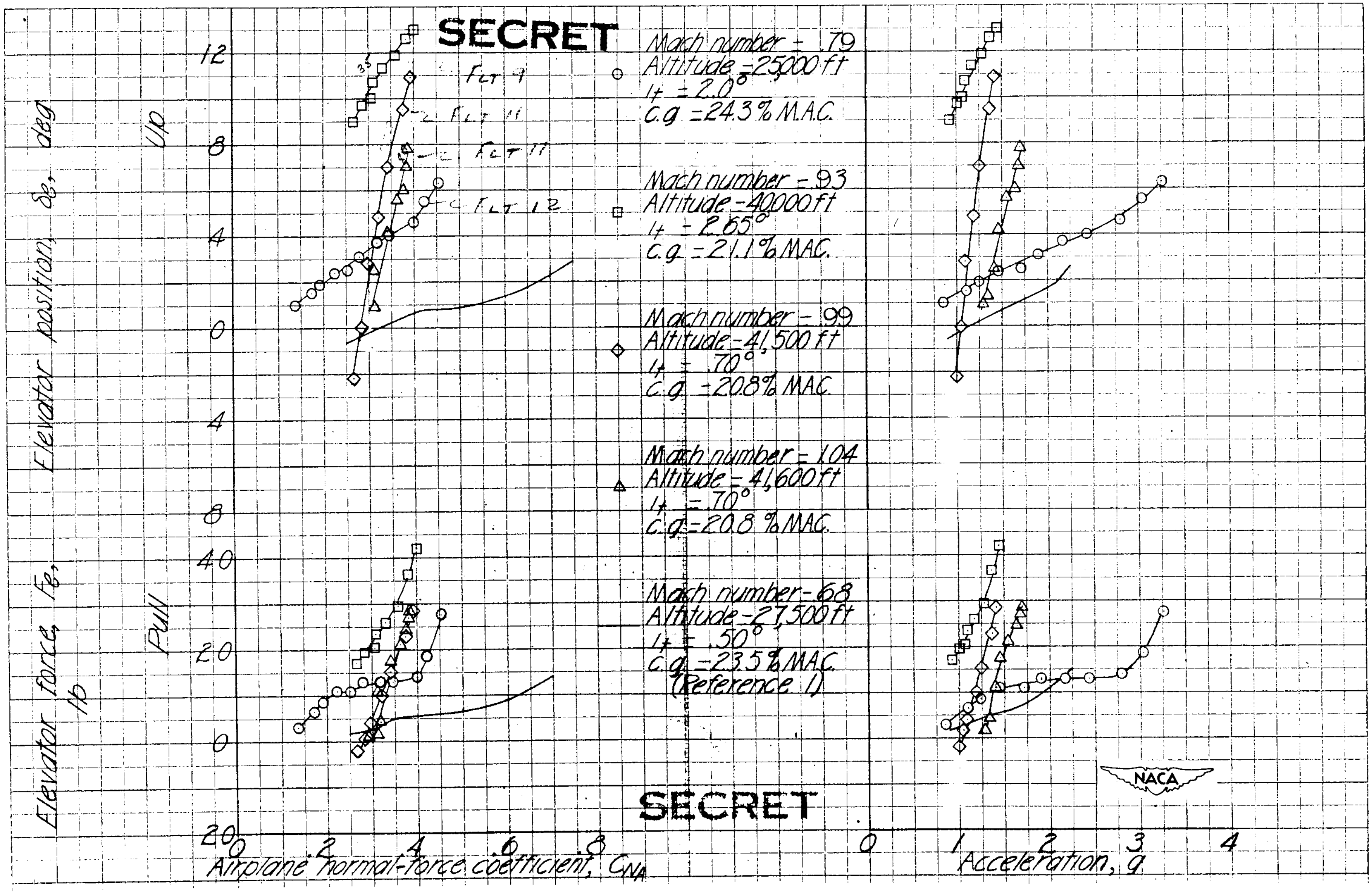

Figure 8.- Control characteristics of XS-1 airplane in accelerated flight.

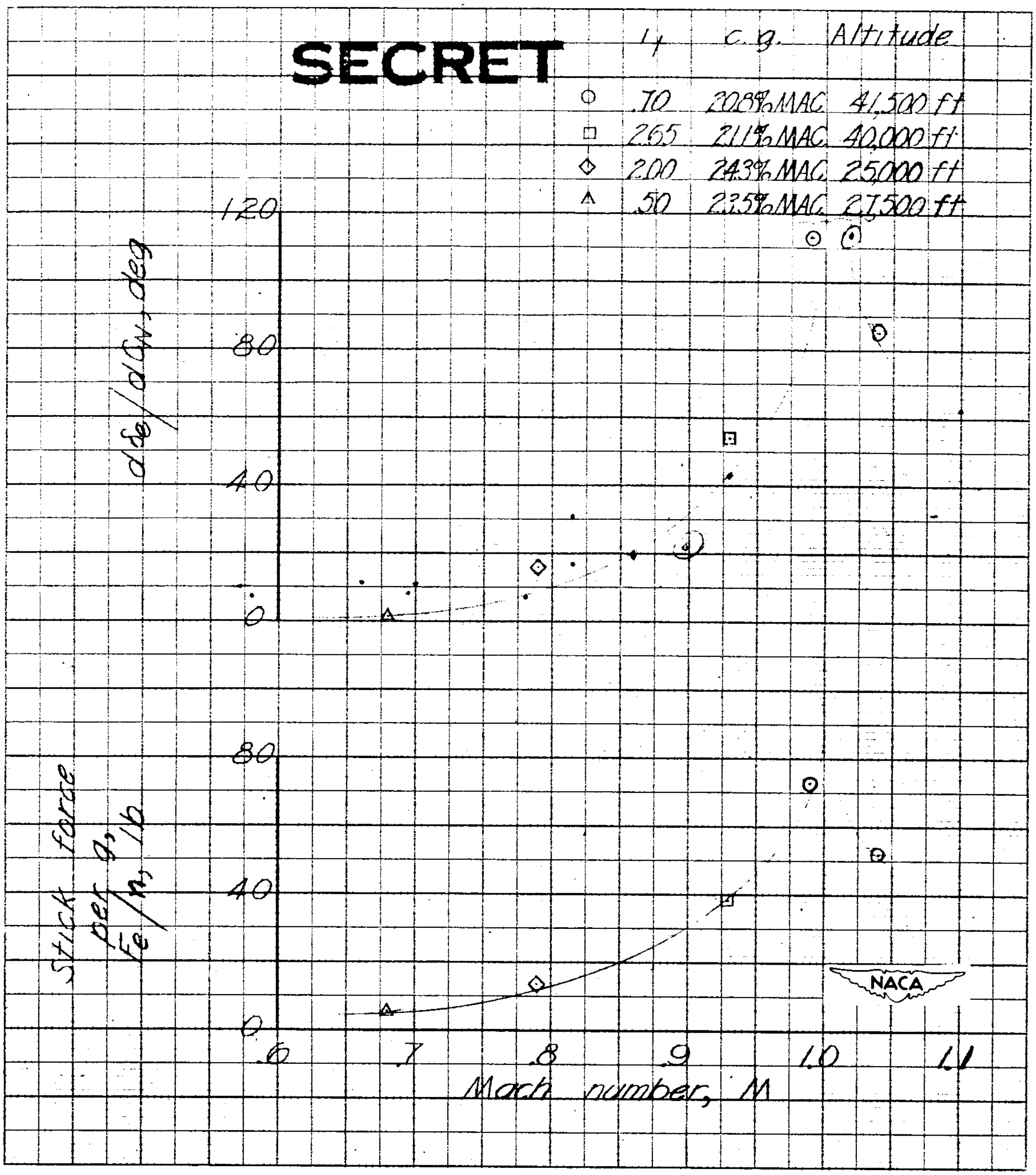

Figure 9.- Variation of longitudinal stability parameters $d\delta_e/dC_N$ and F_e/n with Mach number. XS-1 airplane.